EXHIBIT A

ADVANCED STRUCTURAL MATERIALS

PROPERTIES, DESIGN OPTIMIZATION, AND APPLICATIONS

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9.13.9 Low-Temperature Properties

Aluminum alloys represent a very important class of structural metals for subzero-temperature applications and find use for structural parts for operation at temperatures as low as -270°C (-450°F). Below zero, most aluminum alloys show marginal change in properties, i.e., the yield and tensile strengths may increase resulting in a slight decrease in elongation. Impact strength remains approximately constant. Consequently, aluminum is a useful material for many low-temperature applications. The chief deterrent to its extensive use is its relatively low elongation compared with the austenitic ferrous alloys [67].

9.14 CORROSION BEHAVIOR OF WROUGHT ALUMINUM ALLOYS

Aluminum is an active metal that tends to readily oxidize under the influence of high free energy of the reaction whenever the necessary conditions for oxidation are conducive and/or prevailing. However, overall the alloys of aluminum are stable in most environments due to the rapid formation of a natural oxide of alumina (Al_2O_3) on the surface. Oxide inhibits bulk reaction predicted from thermodynamic data. When the surfaces of aluminum are scratched sufficiently to remove the oxide film, a new film will quickly re-form in most environments. As a rule, the protective film is stable in aqueous solutions of the pH range 4.5–8.5 whereas it is easily soluble in both strong acids and alkalis leading to rapid attack of the aluminum alloy surface. Exceptions are concentrated nitric acid, glacial acetic acid, and ammonium hydroxide.

The oxide film that forms on a freshly rolled aluminum alloy exposed to ambient air is very thin and has been measured to be around 2.5 nm. It tends to grow at a decreasing rate for several years reaching a thickness of some tens of nanometers. The rate of growth of the film becomes rapid at the higher temperatures and at the higher humidities.

The presence of a thicker oxide film gives enhanced corrosion resistance to aluminum and its alloys. Various chemical and electrochemical reagents can produce a thicker oxide film. Natural film can be thickened about 500 times, say 1–2 μm, by immersion of components in certain hot acid and/or alkaline solutions. Although the films produced are mainly Al_2O_3, they also contain chemical such as chromates, which are collected from the bath to render them corrosion resistant.

9.15 RECENT DEVELOPMENTS ON ALUMINUM ALLOYS: ALUMINUM–LITHIUM ALLOYS

With the evolution of technology the conventional aluminum alloys face stiff competition from emerging composite material technologies, particularly in the structural aerospace market. Hybrid materials based on organic and metal matrices with whisker, fiber, or particle ceramic reinforcements offer impressive combinations of strength, stiffness and high temperature resistance [73–78]. Besides, the aramid polymer-reinforced aluminum alloy (ARALL) laminates [79–81] fabricated by resin bonding aramid fibers sandwiched between thin aluminum alloy sheets show exceptional promise as fatigue resistant materials. In light of these advances, the aluminum industry introduced a new generation of aluminum alloys, i.e., the aluminum–lithium alloys obtained by incorporating ultra-low density lithium into traditional aluminum alloys. These alloys were representative of a new class of lightweight, high modulus, high strength, monolithic structural materials, which are cost effective compared to the more expensive composite counterpart [82–92]. Despite the limitations posed by specific-stiffness and high temperature stability, aluminum–lithium alloys enjoy several advantages over the composite materials. Economically, the aluminum–lithium alloys were three times as expensive as conventional high strength aluminum alloys, whereas the competing hybrid materials can be up to 10 to 30 times more expensive [90]. Secondly, the fabrication technology for the lithium-containing aluminum alloys is quite compatible with existing manufacturing methods such as extrusion, sheet forming, and forging to obtain finished products for the conventional